Example 32.87. *An auto-transformer supplies a load of 3 kW at 115 volts at a unity power factor. If the applied primary voltage is 230 volts, calculate the power transferred to the load (a) inductively and (b) conductively.* (Basic Elect. Machines. Nagpur Univ. 1991)

Solution. As seen from Art 32.33

Power transferred inductively = Input $(1 - K)$

Power transferred conductively = Input $\times K$

Now, $K = 115/230 = 1/2$. input $\cong$ output = 3 kW

$\therefore$ Inductively transferred power = $3\,(1 - 1/2) = 1.5$ kW

Conductivley transferred power = $(1/2) \times 3 = 1.5$ kW

Example 32.88. *The primary and secondary voltages of an auto-transformer are 500 V and 400 V respectively. Show with the aid of diagram, the current distribution in the winding when the secondary current is 100 A and calculate the economy of Cu in this particular case.*

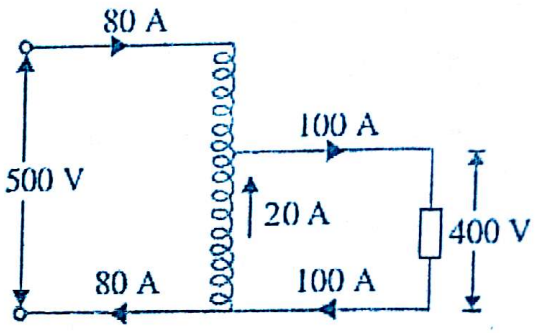

Fig. 32.61

Solution. The circuit is shown in Fig. 30.61.

$K = V_2/V_1 = 400/500 = 0.8$

$\therefore \quad I_1 = KI_2 = 0.8 \times 100 = 80$ A

The current distribution is shown in Fig. 32.61.

Saving = $K W_0 = 0.8\, W_0$ - Art 32.33

$\therefore$ Percentage saving = $0.8 \times 100 = 80$

Example 32.89. *Determine the core area, the number of turns and the position of the tapping point for a 500-kVA, 50-Hz, single-phase, 6,600/5,000-V auto-transformer, assuming the following approximate values : e.m.f. per turn 8 V. Maximum flux density 1.3 Wb/m^2.*

Solution.

$$E = 4.44 f \Phi_m N \text{ volt}$$

$$\Phi_m = \frac{E/N}{4.44 f} = \frac{8}{4.44 \times 50} = 0.03604 \text{ Wb}$$

Core area = $0.03604/1.3 = 0.0277$ m^2 = 277 cm^2

Turns of h.v. side = $6600/8 = 825$: Turns of $L.V.$ side = $5000/8 = 625$

Hence, tapping should be 200 turns from high voltage end or 625 turns from the common end.

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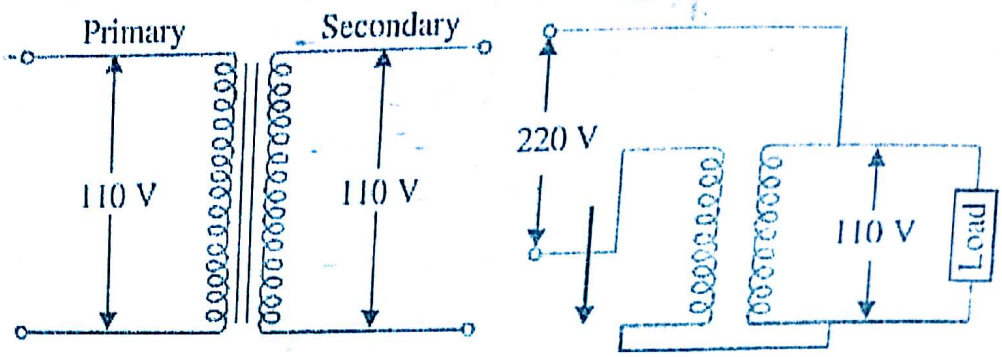
Example 32.92. *A 5-kVA, 110/110-V, single-phase, 50-Hz transformer has full-load efficiency 95% and an iron loss of 50 W. The transformer is now connected as an auto-transformer to a 220-V supply. If it delivers a 5-kW load at unity power factor to a 110-V circuit, calculate the efficiency of the operation and the current drawn by the high-voltage side.*

(Electric Machinery-II, Banglore Univ. 1991)

Solution. Fig. 32.64 (*a*) shows the normal connection for a 2-winding transformer. In Fig. 32.64 (*b*) the same unit has been connected as an auto transformer. Since the two windings are connected in series, voltage across each is 110 V.



(*a*) 2-Winding Transformer (*b*) Auto-Transformer

Fig. 32.64

The iron loss would remain the same in both connections. Since the auto-transformer windings will each carry but half the current as compared to the conventional two-winding transformer, the copper loss will be one-fourth of the previous value.

Two-winding Transformer

$$\eta = 0.95 \qquad \therefore\ 0.95 = \frac{\text{output}}{\text{output + losses}} = \frac{5,000}{5,000 + 50 + \text{Cu loss}}$$

$\therefore$ Cu loss = 212 W

Auto-transformer

Cu loss = 212/4 = 53 W; Iron loss = 50 W $\therefore\ \eta = \dfrac{5,000}{5,000 + 53 + 50} = 0.9797$ or 97.97%

Current of the h.v. side = 5103/220 = 23.2 A

Example 32.93. *A transformer has a primary voltage rating of 11500 volts and secondary voltage rating of 2300 volts. Two windings are connected in series and the primary is connected to a supply of 11500 volts, to act as a step-up auto transformer. Determine the voltage output of the transformer.*

Question extended : If the two winding transformer is rated at 115 kVA, what will be the kVA rating of the auto-transformer ?

(Madras University, 1997)

Solution. As in Fig. 32.65 (*a*). 115 kVA, 11500/2300 V. transformer has the current ratings of 10 A and 50 A.

Referring to Fig. 32.65 (*b*), the step-up connections have been shown. Winding currents have to be at the same rated values. As in Fig. 32.65 (*b*), the voltage obtainable at $B_1 - B_2$ is 13800 *V*, and from b_1 a load-current of 50 A can be supplied.

kVA rating = $13800 \times 50 \times 10^{-3} = 690$

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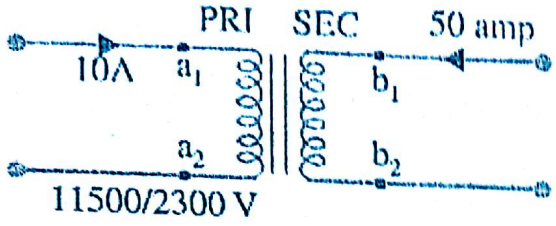
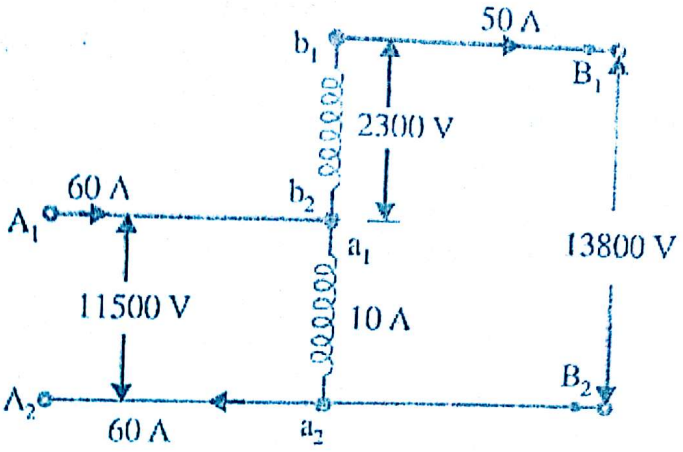


(*b*) 2 winding transformer Rating : 115kVA



(*b*) Auto transformer

Fig. 32.65

Example 32.94. *An 11500/2300 V transformer is rated at 100 kVA as a 2 winding transformer. If the two windings are connected in series to form an auto-transformer, what will be the possible voltage ratios ?* (Manonmaniam Sundaranar Univ. April 1998)

Solution. Fig. 32.66 (*a*) shows this 2-winding transformer with rated winding currents marked.

Rated current of 11.5 kV winding = 100 × 100/11500 = 8.7 Amp

Rated current of 2300 V winding = 43.5 Amp

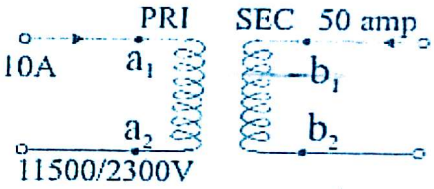


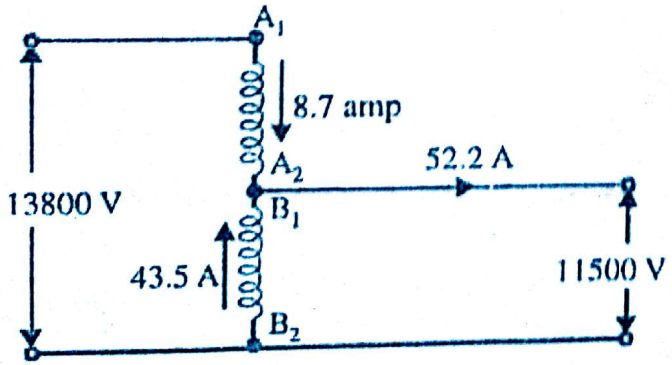
Fig. 32.66 (*a*). 2 winding transformer

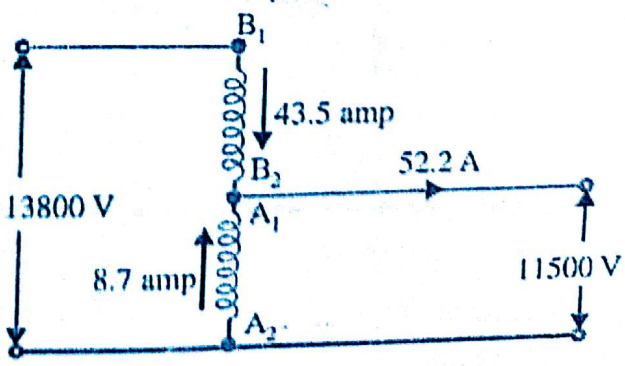
Fig. 32.66 (*b*) and Fig. 32.66 (*c*) show autotransformer connections. On H.V. side, they have a rating of 13.8 kV. On L.V. side, with connection as in Fig. 32.66 (*b*), the rating is 2300 V. On L.V. side of Fig. 32.66 (*c*), the output is at 11.5 kV.

Thus, possible voltage ratios are : 13800/2300 V and 13800/11500 V.

With both the connections, step-up or step-down versions are possible.

Extension of Question : Calculate kVA ratings in the two cases.





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Windings will carry the rated currents. while working out kVA outputs.

In Fig. 32.66 (*b*). Input current (into terminal A_1 of windings A_1-A_2) can be 8.7 Amp with H.V.-s voltage ratings as 13.8 kV. Transformation ratio = 13800/2300 = 6

Hence. kVA rating = $13.8 \times 8.7 = 120$

Output current = $120 \times 1000/2300 = 52.2$ Amp

Current in the winding B_1-B_2

= Difference of Output current and Input current

= 52.2 – 8.7 = 43.5 A. which is the rated current of the winding B_1-B_2.

In Fig. 32.66 (*c*). Similarly. transformation ratio = 13800/11500 = 1.2

kVA rating = $13800 \times 43.5 \times 10^{-3} = 600$

Output current = $600 \times 1000/11500 = 52.2$ Amp

Current carried by common winding = 52.2 – 43.5 = 8.7 A. which is rated current for the winding A_1-A_2. Thus. with the same two windings give. a transformation ratio closer to unity gives higher kVA rating as an auto transformer.

Thus. a 100 kVA two winding transformer is reconnected as an autotransformer of 120 kVA with transformation ratio as 6. and becomes a 600 kVA autotransformer with transformation ratio as 1.2.

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(4.) $\eta = \dfrac{n V_2 I_2 \cos\phi_2}{n V_2 I_2 \cos\phi_2 + P_i + n^2 P_c}$

$$0.9877 = \frac{400 \times 0.8}{400 \times 0.8 + P_i + P_c}$$

$$P_i + P_c = \frac{400 \times 0.8}{0.9877} - 400 \times 0.8 = 323.985 - 320$$

$$\boxed{P_i + P_c = 3.985 \text{ kW}}$$

$$P_i + P_c = 3985 \text{ watt}$$

$$0.9913 = \frac{200 \times}{200 + P_i + 0.25 P_c}$$

$$P_i + 0.25 P_c = \frac{200}{0.9913} - 200 = 1.7553 \text{ kW}$$

$$P_i + 0.25 P_c = 1755 \text{ W}$$

$$0.75 P_c = 2230 \text{ W}$$

$$\boxed{\begin{aligned} P_c &= 2973 \text{ W} \\ P_i &= 1012 \text{ W} \end{aligned}}$$

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(17) $P_{cu} = 1600\ W$

150 kVA, 11000/230 V

$$n = \sqrt{\frac{P_i}{P_{cu}}} = \sqrt{\frac{1400}{1600}} = 0.935$$

$$\eta = \frac{150 \times 0.8 \times 0.935}{150 \times 0.8 \times 0.935 + 1400 + (0.935)^2 \times 1600}$$

$$= \frac{112.2}{112.2 + 2800} \times 100$$

Load = 112.2 kW

$$\eta = \frac{112.2}{112.2 + 2.8} \times 100 = \boxed{97.56\%}$$

$$\eta = \frac{112.2 \times 0.5}{56.1 + 1400 + 400}$$

$$= 96.89\%$$

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0.98 100 0.5 0.51 2.04

Time	Load	PF	ENERGY	P(Iron)	E (Iron losses)	n	PCU	E(copper losses)
Hours	KVA		KWH	KW	KWH		KW	KWH
8	100	1.00	800	0.51	4.08	1.00	2.04	16.33
6	50	0.80	240	0.51	3.06	0.50	0.51	3.06
10	0	0.00	0	0.51	5.10	0.00	0	0
		Total	1040		12.24			19.39
		eff	0.970					

Problem 13

Time	Load	PF	ENERGY	P(Iron)	E (Iron losses)	n	PCU	E(copper losses)
Hours	KVA		KWH	KW	KWH		KW	KWH
6	400	0.80	1920	3.5	21	0.80	2.88	17.28
10	300	0.75	2250	3.5	35	0.60	1.62	16.2
4	100	0.80	320	3.5	14	0.20	0.18	0.72
4	0	0.00	0	3.5	14	0.00	0	0
		Total	4490		84			34.2
		eff	0.974					

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EE352

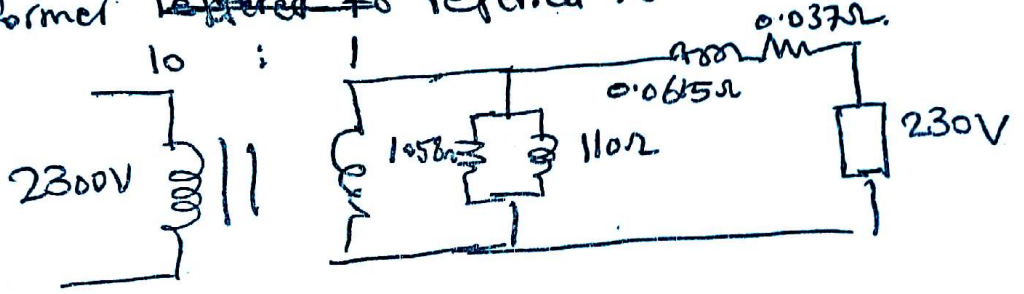
Q1/ A 15 KVA 2300/230 V single phase transformer is to be to determine its excitation branch components, its series imp. and its voltage regulation. The following test data have been taken from the primary side of the transformer.

(a) i

open circuit test
V = 2300 Volt
I = 0.21 A
P = 50 W

short-circuit test
V = 47 Volt
I = 6.52 A
P = 160 W

(a) Draw the exact equivalent circuit showing all values of this transformer ~~referred to~~ referred to low voltage side?



(b) Calculate the full load voltage regulation at 0.8 lagging power Factor

$$\text{Voltage regulation} = \frac{I_1 (R_{e1}\cos\phi_2 + X_{e1}\sin\phi_2)}{V_1}$$

$$\text{Voltage regulation} = \frac{6.257\,(0.0615 \times 0.8 + 0.037 \times 0.6)}{230} = 1.94\%$$

or

$$\text{Voltage regulation} = \frac{V_{sc}\cos(\phi_e - \phi_2)}{V_1} = \frac{47\cos(58.5 - 36.87)}{2300} = 1.9\%$$

(c) Calculat the Voltage at the secondary side at full load.

Voltage at the secondary = $230 - (0.0194 \times 230) = 225.54$ Volt.

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$$\frac{n\,S\cos\theta}{n\,S\cos\theta + n^2 P_{cu} + P_{iron}} \times 100 = \frac{0.6 \times 15000 \times 0.8}{(0.6 \times 1500 \times 0.8) + 50 + (0.6)^2 (160)} \times 100$$

$$\boxed{\eta\% = 98.52\%}$$

(e) what is the maximum efficiency?.

∴ at maximum efficiency $P_{iron} = n^2 P_{cu}$.

$$\therefore n = \sqrt{\frac{P_{iron}}{P_{cu}}} = \sqrt{\frac{50}{160}} = 0.559.$$

$$\therefore \eta\% = \frac{0.56 \times 15000 \times 0.8}{0.56 \times 15000 \times 0.8 + 50 + 50} \times 100 = 98.53\%$$

Q2

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400KVA distribution transformer has full load iron loss of 2.5kW and copper loss of 3.5kW. During day, its load cycle for 24 hour is:

6 hours 300kW at 0.8 PF.
10 hours 200kW at 0.7 PF
4 hours 100kW at 0.9 pf.

Determine its all day efficiency

Solution

$P_i = 2.5kW$, $P_{cu}(F.L) = 3.5kW$, 400KVA.

Iron loss is constant for 24 hours. So energy spent due to iron loss for 24 hours is:-

$$P_{iron} = 2.5 \times 24 = 60kWh.$$

Total Energy output in a day from given load cycle is

$$\text{Energy output} = 300 \times 6 + 200 \times 10 + 100 \times 4 = 4200kWh$$

To calculate energy spent due to copper loss.

(1) Load (1) of 300kW at 0.8 PF.

$$KVA\,supplied = \frac{kW}{PF} = \frac{300}{0.8} = 375KVA.$$

$$n = \frac{\text{load KVA}}{\text{rating KVA}} = \frac{375}{400} = 0.9375.$$

Copper losses are proportional to square of KVA. ration i.e n^2.

$$\text{Load 1 } P_{cu} = n^2 \cdot P_{cu}(F.1) = (0.9375)^2 \times 3.5 = 3.076kW$$

$$\text{Energy spent} = 3.076 \times 6 = 18.457kWh.$$

2) Load (2) of 200kW at 0.7 PF.

$$KVA\,supplied = \frac{kW}{\cos\theta} = \frac{200}{0.7} = 285.7142KVA$$

$$n = \frac{\text{Load KVA}}{\text{rating KVA}} = \frac{285.7142}{400} = 0.7142.$$

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Energy Spent = 1.7857 X 10 = 17.857 kWh.

Load (3) of 100kVA at 0.9 pf.

$$\text{KVA Supplied} = \frac{kW}{\cos\phi} = \frac{100}{0.9} = 111.111 \text{ KVA}$$

$$n = \frac{111.111}{400} = 0.2778$$

$$\text{Load (3) } P_{cu} = n^2 (P_{cu})_{F.L} = (0.2778)^2 \times 3.5 = 0.2701 \text{ kW}$$

Energy Spent = 0.2701 X 4 = 1.0804 kWh.

Assume No load hece negligible copper loss.

Total Energy Spent = Energy spent due to (iron loss + Copper loss)

24 × 1/12

= 60 + 18.57 + 17.857 + 1.0804 = 97.3974 k

Total output = 4200kWh.

$$\text{All day } \eta = \frac{\text{Total output for 24h}}{\text{Total output for 24h} + \text{Total Energy Spent for 24hr}} \times 100$$

$$\text{All day } \eta = \frac{4200}{4200 + 97.3974} \times 100 = 97.73\%$$

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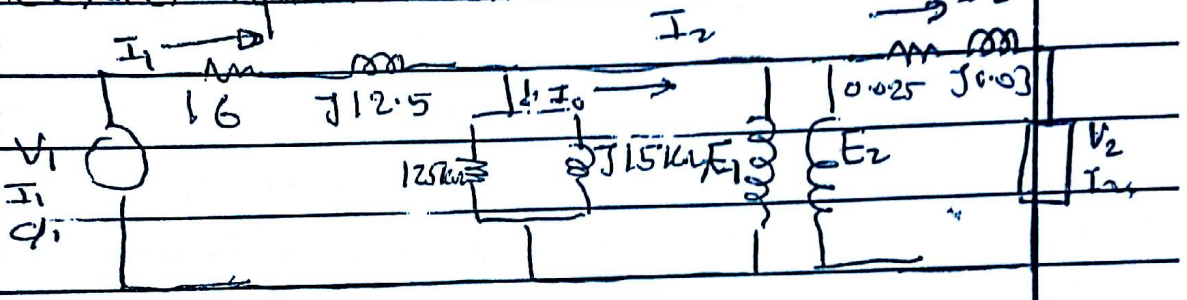
2/4/2017

Tutorial #2 EE352

Q1 50 KVA, 50 Hz supply, 2200/132V single phase transformer with a (16+J12.5) primary impedance and (0.025+j0.03) secondary impedance. The primary side shunt has (125KΩ) core resistance and (J15KΩ) magnetizing reactance. Find

(a) The exact equivalent circuit



(b) The maximum primary induced emf1 for rated load at 132 V and 0.85 lagging PF.

$E_1 = ?$ $\Rightarrow E_1 = E_2 \times \frac{V_1}{V_2}$

$E_2 = V_2 + I_2 Z_2$, $I_2 = \frac{50\text{KVA}\ \angle -\cos^{-1}0.85}{132}$

$$I_2 = 378.78\ \angle -31.79 \longrightarrow (1)$$

$$E_2 = 132\ \angle 0 + (378.78\ \angle -31.79)(0.025+j0.03)$$

$$E_2 = 146.45\ \angle 1.87 \longrightarrow (2)$$

$$E_1 = E_2 \times \frac{V_1}{V_2} = 146.45\ \angle 1.87 \times \frac{2200}{132} = 2441\ \angle 1.8\ \text{(RMS)}$$

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$E_{1max} = \sqrt{2}\, E_{rms} = 3452\ V$

(c) The supply voltage for the same operating conditions:

$V_1 = E_1 + I_1 Z_1$.

$I_1 = I_0 + I_2'$, $I_2' = I_2/a = 22.72 \angle -31.79$ A.

$I_0 = \frac{E_1}{(j15k\Omega // -j25k\Omega)} = 0.1634 \angle -81.328$

$I_1 = I_2 + I_0 = 22.836 \angle -32.27$ A.

$V_1 = 2441 \angle 1.87 + (22.836 \angle -32.27)(20.3 \angle 38)$

$\boxed{V_1 = 2897 \angle 2.8^\circ}$

(d) The maximum flux established per turn:

$E_1 = 4.44\, \Phi_{max}\, f\, N_1$

$\frac{\Phi_{max}}{turn} = \frac{E_1}{4.44 f N_1} = \boxed{\frac{10.96\ mb}{N_1\ t}}$

OR

$\boxed{\frac{\Phi_{max}}{turn} = \frac{E_2}{4.44 f N_2}}$

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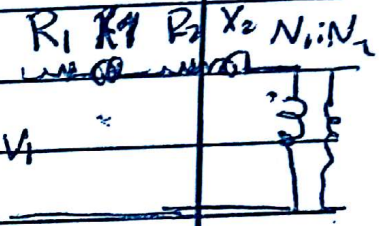
100KVA transformer has 400 turn on the primary and 80 turns on the Secondary. The primary and Secondary resistances are 0.3Ω, $R_2 = 0.01\Omega$ and corresponding leakage reactance's are 1.1Ω and 0.035Ω. The Supply Voltage is 9200V. The iron loss is 600 watt Calculate.

(a) The equivalent impedance referred to primary

$$a = \frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{80}{400} = \frac{1}{5}$$

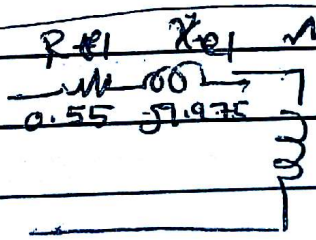


$$R_2' = \frac{R_2}{a^2} = \frac{0.01}{(1/5)^2} = 0.22\Omega.$$

$$\therefore R_{e1} = R_1 + R_2' = 0.22 + 0.3 = 0.55\Omega$$

$$X_2' = \frac{X_2}{a^2} = \frac{0.035}{(1/5)^2} = 0.875\Omega.$$

$$\therefore X_{e1} = X_1 + X_2' = 0.875 + 1.1 = 1.975\Omega$$



$P_{iron} = 600$ watt

$P_{cu} = I_1^2 R_{e1} = I_2'^2 R_e$

(b) The efficiency at full load and 0.8 PF lagging.

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$I_1 = \frac{100000}{2200} = 45.45\ A.$

$P_{cu} = I_1^2 R_{e1} = (45.45)^2 \cdot (0.55) = 1136.363\ Watt.$

or by eq

$\eta = \frac{S\cos\theta}{S\cos\theta + P_i + P_{cu}} = \frac{80000}{80000 + 600 + 1136.36}$

$\eta = 0.978 \Rightarrow \eta\% = 97.8\%$

(e) The maximum efficiency at 0.9 PF leading

$n = \sqrt{\frac{P_i}{P_{cu}}} = \sqrt{\frac{600}{1136.363}} = 0.7266$

$\eta_{max} = \frac{n \times S\cos\theta}{n \times S\cos\theta + 2P_i} = \frac{0.7266 \times 100 \times 10^3 \times 0.9}{0.7266 \times 100 \times 10^3 \times 0.9 + 1200}$

$\eta_{max} = 0.9819. \Rightarrow \eta_{max}\% = 98.19\%$

d) The voltage regulation at full load and (0.8 lagging and 0.9 leading)

$\epsilon\% = \frac{I_1 (R_{e1}\cos\phi \mp X_{e1}\sin\phi)}{V_1} \times 100$

For lagging 0.8 PF.

$\epsilon\% = \frac{45.45 (0.55 \times 0.8 + 1.975 \times \sin\cos^{-1} 0.8)}{2200} \times 100$

$\epsilon\% = 3.357\ \%$

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For Leading 0.9 pf

$$\%\varepsilon = \frac{45.45 \times (0.55 \times 0.9 - 1.975 \sin(\cos^{-1} 0.9))}{2200}$$

$$\%\varepsilon = -0.7558\ \%$$

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